Distributed Systems

Client-Server Models and Code Migration

WEEK 5: Client-Server Model, Code Migration, Mobile Code, Remote Execution, Distributed Application

Online Lecture Series - 5

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Content Outline

Topics We Will Cover

- **Client-Server Model** — Request/response, real-world examples
- **Code Migration** — Motivation, strong vs. weak migration
- **Mobile Code** — Benefits, risks, use cases
- **Remote Execution** — Offloading computation, cloud services
- **Distributed Application** — Features, examples, scalability

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Client-Server Model

Key Points

- A distributed model where **clients request services** and **servers provide them**.
- Widely used in distributed systems and the Internet.
- Separates responsibilities: servers manage resources; clients consume them.

Example

- A web browser (client) requests a webpage from a web server.

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Client-Server Model: Industrial Examples

Real-World Applications

- **Banking Systems** — ATMs (clients) connect to central banking servers.
- **E-Commerce** — Clients (apps/websites) request product data from backend servers.
- **Cloud Services** — Clients use cloud APIs while servers handle computation/storage.

Observation

- The model is scalable but can face bottlenecks if the server is overloaded.

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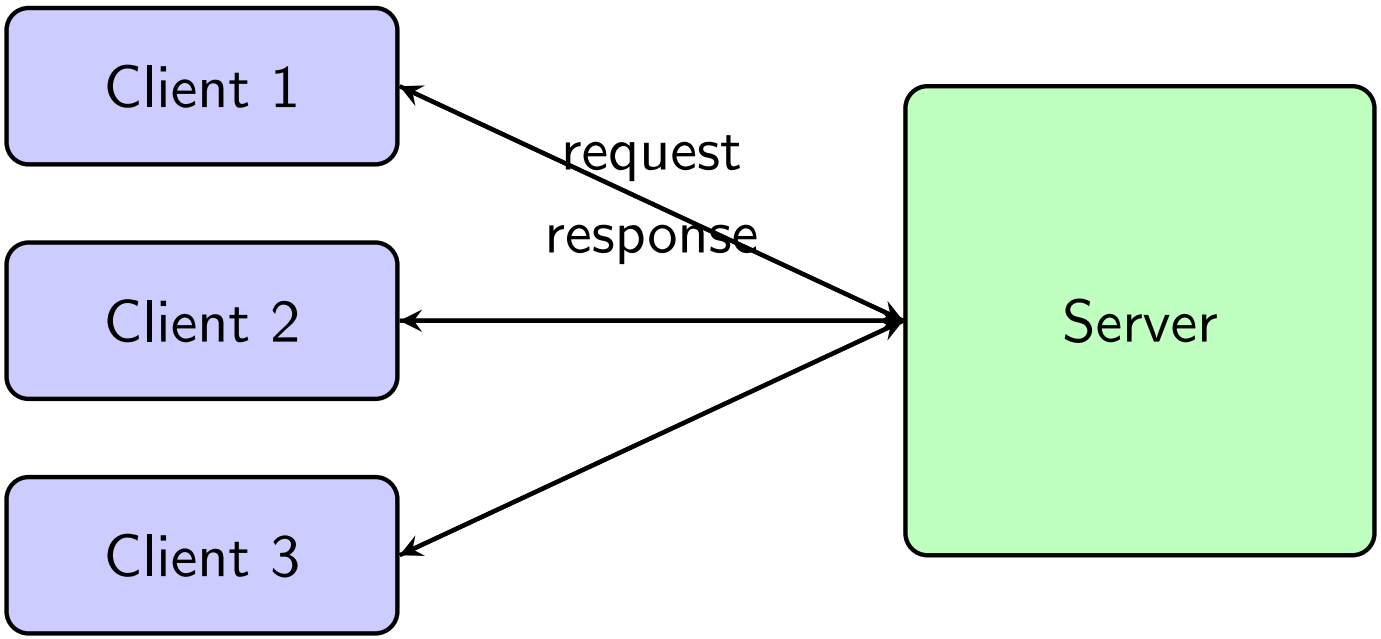
Client-Server Model: Diagram



Advantages of Client-Server Model

Key Benefits

- **Centralized Control** – easier to manage security, backups, and updates.
- **Resource Sharing** – multiple clients can access the same data/services.
- **Scalability** – servers can be upgraded to handle more clients.

Example

- A university server hosting course materials for thousands of student clients.

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Limitations of Client-Server Model

Challenges

- **Single Point of Failure** – if the server crashes, all clients are affected.
- **Performance Bottleneck** – heavy load on server reduces responsiveness.
- **Maintenance Cost** – requires reliable server hardware and skilled admins.

Industrial Example

- Online banking downtime: a central server failure can block millions of transactions.

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Practical Example: Web Application

How It Works

- A user opens a browser (client) and requests `www.shop.com`.
- The request is sent to the server hosting the e-commerce website.
- The server processes the request and returns the product page.

Illustration

- **Client** = Web browser
- **Server** = Apache/Nginx hosting the online shop

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Client-Server in Industry

Examples

- **Healthcare** – doctors' terminals accessing patient databases on a central server.
- **Retail** – POS (Point of Sale) systems transmitting sales data to a central server.
- **Streaming Services** – Netflix servers deliver video content to client devices.

Observation

- Reliable, manageable, and scalable — ideal for mission-critical operations.

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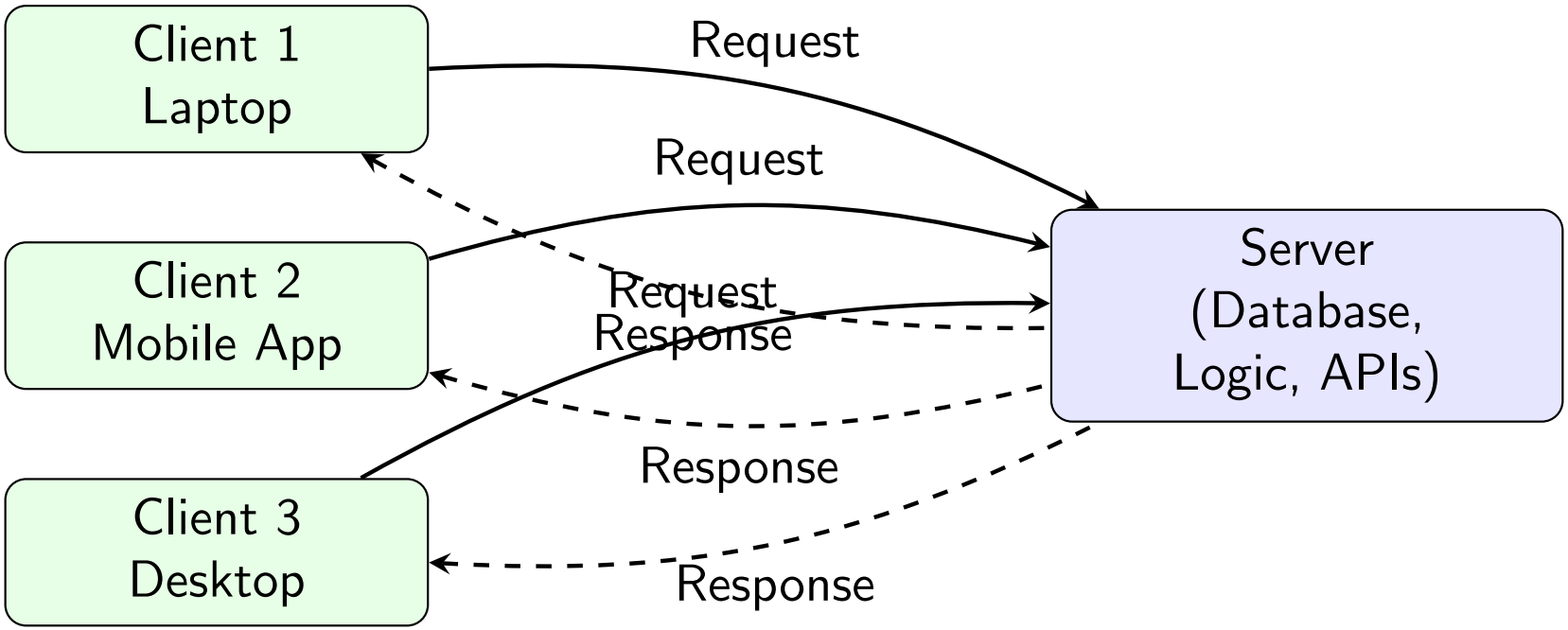
Client-Server Architecture Diagram



Clients send requests and receive responses from the central server using a request-response model.

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Code Migration

Key Idea

- Code migration refers to moving programs or code segments from one machine to another during execution.
- Enables distributed systems to improve flexibility, load balancing, and performance.

Practical Example

- A web service dynamically moves a computation-heavy process to a more powerful remote server.

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Why Code Migration Matters

Motivations

- **Performance Optimization** – move computation closer to data.
- **Load Balancing** – distribute workload among multiple servers.
- **Fault Tolerance** – recover by migrating tasks from failed nodes.
- **Software Updates** – update or patch running systems dynamically.

Example

- Cloud-based video rendering tasks are moved between servers to minimize latency.

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Forms of Code Migration

Main Types

- **Weak Mobility** – only the code moves; execution restarts on the target machine.
- **Strong Mobility** – code and execution state move together and resume remotely.

Industrial Example

- Java Applets (weak mobility) – downloaded and executed on a client browser.
- Mobile Agents (strong mobility) – systems like IBM Aglets migrate active agents.

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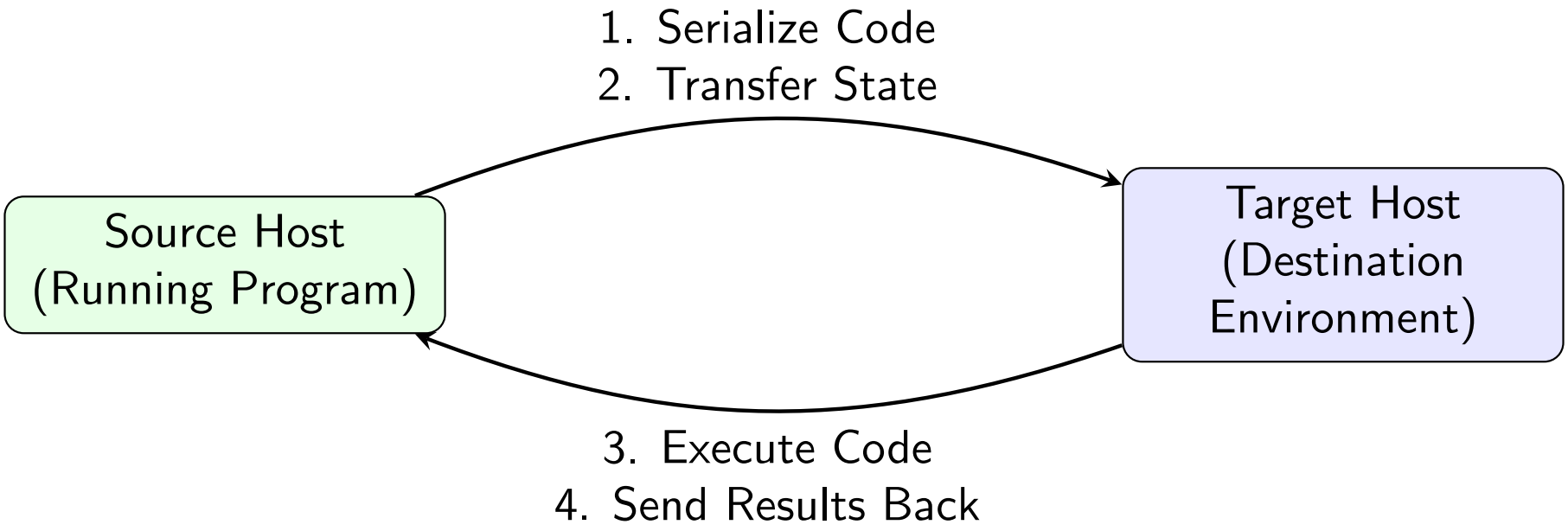
Code Migration Process



Execution context
is transferred to a remote host
for processing and
results are sent back.

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Models of Code Migration

Execution Models

- **Remote Execution Model** – client sends computation to a powerful server.
- **Code-on-Demand Model** – server sends code to a client for local execution.
- **Mobile Agent Model** – code moves autonomously across hosts.

Example

- In web applications, JavaScript is downloaded (code-on-demand) and runs in the browser.

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Practical Example: Distributed Computation

Scenario

- A scientific computation platform offloads heavy tasks (e.g., simulation, rendering) to remote clusters.
- Each task migrates with its code and state, executes remotely, and sends results back.

Industrial Example

- SETI@home and Folding@home use distributed code migration for large-scale computation.

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Advantages and Challenges

Advantages

- Improved performance and resource utilization.
- Enhanced flexibility and scalability.
- Reduces data transfer by moving computation closer to data.

Challenges

- Security and trust issues in host environments.
- Handling heterogeneous architectures.
- Managing failures during migration.

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Summary of Code Migration

Essence

- Code migration makes distributed systems more adaptive and efficient.
- Commonly used in cloud computing, web systems, and mobile agents.
- Strong and weak mobility differ in how much state is transferred.

Looking Ahead

- Next: **Mobile Code** — how code travels autonomously and executes across heterogeneous systems.

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Optimal Migration Decision

Goal

- Determine whether migrating computation improves overall performance.
- Let T_l = local execution time, T_m = migration overhead, and T_r = remote execution time.

Decision Rule

Migrate if $T_m + T_r < T_l$

- T_m includes transfer, initialization, and re-synchronization costs.

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Python Demo: Code Migration Concept

Overview

- Demonstrates how computation can be migrated to another machine.
- Used in distributed systems for offloading tasks to remote nodes.
- Mimics how cloud functions or containers execute workloads remotely.

Goal

- Understand the process of sending code to a remote system for execution.
- Observe how results are returned to the local client.

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Code Migration: Setup Requirements

Environment Setup

- Python installed on both local and remote machines.
- Remote host must allow SSH connections.
- Install library: `pip install paramiko`.

Execution Flow

1. Connect securely to remote server via SSH.
2. Send code as a command to be executed.
3. Retrieve and display output locally.

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Code Migration via SSH: Shell Example

SSH Remote Execution

- Connect to a remote server:

```
ssh username@remote_host
```

- Send and execute a Python script remotely:

```
scp my_script.py username@remote_host:/tmp/
ssh username@remote_host python3 /tmp/my_script.py
```

- Optional: capture output locally

Python Example: Remote Execution (Part 1)

Define Remote Execution Function

```
import paramiko
def remote_execute(host, user, password, code):
    ssh = paramiko.SSHClient()
ssh.set_missing_host_key_policy
   (paramiko.AutoAddPolicy())
    ssh.connect(host, username=user,
   password=password)
    stdin, stdout, stderr = ssh.exec_command(code)
    out, err = stdout.read().decode(),
   stderr.read().decode()
    ssh.close(), return out, err
```

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Python Example: Remote Execution (Part 2)

Run and Retrieve Results

```
# Example: Migrate computation to remote host
code_to_run = print('Running remotely...')
out, err = remote_execute(
    '192.168.1.10', 'user', 'password',
    code_to_run
)
print("Output:", out)
if err:
    print("Error:", err)
```

Code is executed on a remote system — a simple simulation of code migration.

Mobile Code in Distributed Systems

Definition

- Mobile code refers to programs or scripts that **move across network nodes** and execute on remote machines.
- Unlike traditional code, it is **not bound to the originating host**.

Key Features

- **Portability:** Can run on different hosts with compatible runtime.
- **Autonomy:** Carries logic and instructions along with data.
- **Dynamic Deployment:** Can be sent and executed at runtime without pre-installation.

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Mobile Code: Benefits

Key Advantages

- **Flexibility** — Code can move to the location where resources or data reside.
- **Reduced Network Load** — Instead of transferring large datasets, send code to the data.
- **Dynamic Updates** — Systems can update behavior at runtime without restarting clients.

Example

- A monitoring script that moves to different servers to collect metrics instead of central polling.

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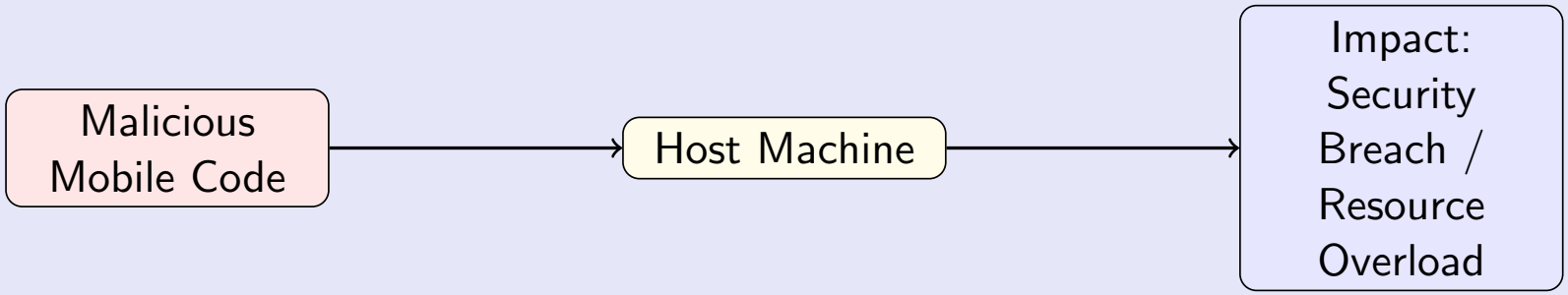
Mobile Code: Risks

Challenges and Risks

- **Security Threats** — Malicious code could compromise host machines.
- **Compatibility Issues** — Different runtime environments may break code execution.
- **Resource Overuse** — Mobile code could consume CPU, memory.

Diagram: Risk Flow



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Mobile Code: Use Cases

Practical Applications

- **Distributed Monitoring** — Code moves to servers to collect logs and metrics locally.
- **Content Distribution** — Scripts for updating software or configurations on client machines.
- **IoT Devices** — Code is sent to sensors or embedded devices to update behavior remotely.

Industrial Example

- Smart home systems send small programs to devices to adjust behavior based on user preferences dynamically.

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Remote Execution in Distributed Systems

Definition

- Remote execution allows a program or task to **run on a different machine** than the one where it originated.
- Enables **load balancing, parallel processing, and resource optimization**.

Key Points

- Typically requires **network connectivity** and a compatible execution environment.
- Can be **synchronous** (waits for completion) or **asynchronous** (fires and forgets).

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Benefits of Remote Execution

Advantages

- **Resource Utilization:** Leverage idle machines for computation.
- **Scalability:** Run tasks on powerful remote servers.
- **Flexibility:** Deploy updates or patches without touching local systems.

Practical Example

- Running large data analysis on a remote cloud server instead of a local laptop.
- System administrators executing scripts on multiple servers via SSH.

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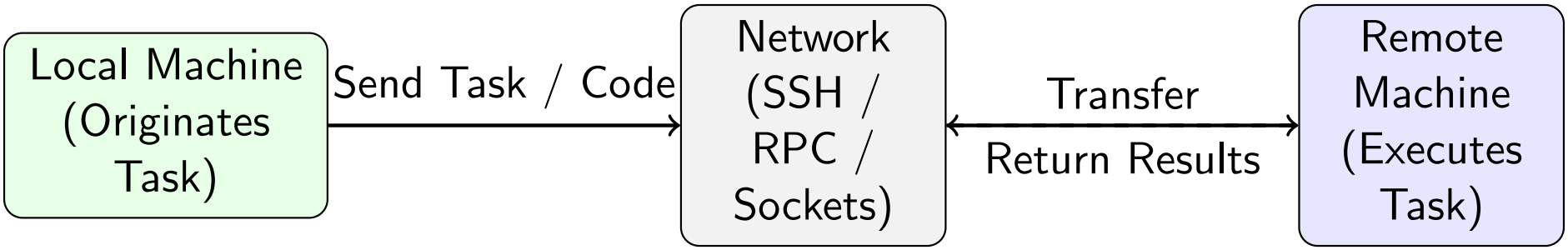
Remote Execution: Conceptual Diagram



Distributed Applications: Overview

Definition

- Applications where components run on multiple networked computers but appear as a single coherent system to users.
- Aim: improved performance, fault-tolerance, and scalability.

Key Features

- Concurrency: multiple processes run simultaneously.
- Transparency: location, replication, and access are hidden from the user.
- Scalability: system can grow without affecting functionality.

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Distributed Applications: Examples

Industry Examples

- **Online Banking** — transactions processed across multiple servers for reliability.
- **E-commerce Platforms** — Amazon, eBay: multiple servers handle catalogs, orders, payments.
- **Streaming Services** — Netflix, YouTube: content delivery via distributed nodes for low latency.
- **Collaborative Tools** — Google Docs, Zoom: distributed processing for real-time collaboration.

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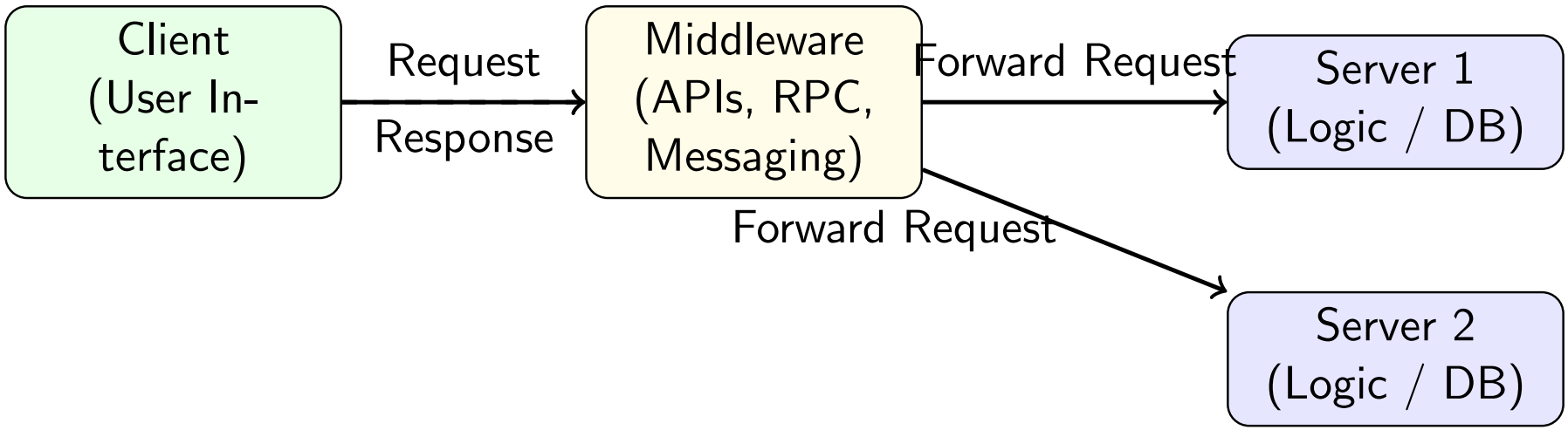
Distributed Application Architecture



Benefits of Distributed Applications

Key Advantages

- **Fault Tolerance** — if one node fails, others can continue processing.
- **Load Balancing** — distribute tasks to prevent bottlenecks.
- **Scalability** — new nodes can be added to handle increasing demand.
- **Resource Sharing** — multiple users share the same resources efficiently.

Example

- Content Delivery Networks (CDNs) like Akamai serve millions of users simultaneously with distributed servers.

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Risks and Challenges of Distributed Applications

Common Issues

- **Network Latency** — delays due to communication over distributed nodes.
- **Consistency** — ensuring all nodes have the same view of data.
- **Security** — data may traverse insecure networks
- **Debugging Complexity** — harder to track errors across multiple machines.

Industrial Example

- Banking system updates must be synchronized across multiple branches to prevent inconsistent account balances.

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Questions?

Thank you for your attention!

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References

Suggested References

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